Ballistic Missile Defense Organization
2001 Technology Applications Report

On January 2, 2002, the Ballistic Missile Defense Organization (BMDO) officially became the Missile Defense Agency (MDA). This change reflects the elevated national priority and mission emphasis of missile defense for the U.S., deployed forces, allies, and friends.

Missile Defense Agency

Introduction

BMDO Nurtures Far-Reaching Technology Advances.
The Ballistic Missile Defense Organization (BMDO) invests in new innovative technologies to help defend the United States, its allies, and its friends from increasingly sophisticated ballistic missile threats. From its inception, BMDO and its predecessor, the Strategic Defense Initiative Organization (SDIO), have supported the development of these technologies for direct integration into weapon systems as well as for spinoffs into commercial applications. The commercial market oftentimes provides the right environment to mature leading-edge technologies that may be too risky or unproven for missile defense.

To help BMDO-funded developers find commercial niches for their technologies, BMDO created the Technology Applications (TA) program. This program works to leverage the power of the commercial marketplace to speed development, prove reliability, lower cost, and provide funding for technologies. It helps companies find ways to bridge the gap between weapon system R&D and technology acquisition, which can be years apart.

The TA program uses several approaches to assist BMDO-funded companies commercialize their technologies. Newly funded companies sometimes need help "thinking commercially" as they launch into their research areas. The TA program offers early-stage technology developers a full-day planning session, which culminates in them developing personalized road maps to commercializing their technologies. These efforts are supported by a staff of technology engineers who can "talk shop" with the researchers, enabling them to jointly discover the commercial potential of a technology innovation. For developers with technology beyond the start-up phase, the TA program offers a more in-depth technology review to help them take the final leap into commercialization. An engineering staff supports this activity along with a panel of selected industry and financial experts who volunteer their time to advise the presenters.

Other TA program functions include developing targeted publications to raise industry and public awareness and participating in specialized outreach activities such as trade shows and industry meetings. With a staff of professional science writers, a quarterly newsletter is written, produced, and distributed, along with periodic focused reports, brochures, and special publications. In addition,Web sites have been developed and are maintained. The newsletter has a qualified circulation of more than 7,000 readers and is used as a tool to raise the visibility of BMDO-funded technologies, leading to valuable commercial partnerships. Regular readers of the newsletter include business executives, venture capitalists, private investors, consultants, state and local economic development groups, government officials, and press who disseminate the information to their own audiences. Application- or industry- focused reports are also an important way to provide specific information about BMDO-funded technologies. Examples of special reports include two written for the fiber-optic telecommunications industry, one on technologies that can help with aviation safety, several that focus on technologies that can help the biomedical community, and even one on technologies well-suited for environmental applications.

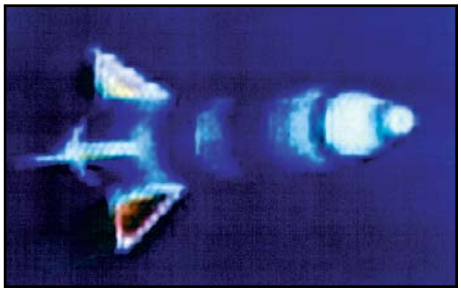
In addition, information on BMDO technology and its TA program are featured on two Internet Web sites. BMDO's official site is BMDOLINK (located at http://www.acq.osd.mil/bmdo/bmdolink/html/ bmdolink.html) and a standalone TA program site is located at www.bmdotechnology.net.

The *2001 Technology Applications Report* features BMDO investments that have met commercial success, are being used in military systems, or both. Highlighted technologies are grouped into four sections: computing and communications, materials, sensors and tracking, and energy and propulsion.

■ **BMDO Looks to Small Businesses for Innovative Solutions.** Many of the technologies promoted by the Technology Applications program were originally funded by BMDO Small Business Innovation Research (SBIR) contracts. Congress mandated SBIR to stimulate the economy by supporting entrepreneurs and their high-risk, high-reward ideas. Across all government agencies, the SBIR program funds technologies that are so risky and potentially innovative they would not likely attract commercial interest or near-term government funding.

Since its inception in 1985, BMDO has pursued a seed capital approach to its SBIR program. All of the technologies funded by the BMDO SBIR program support advanced ballistic missile defense. Most, however, are not likely to reach a ballistic missile defense (BMD) system for 7 to10 years from technology demonstration. To stay alive, these small companies may need commercial outlets for their ideas.

■ **A New Threat for BMDO to Manage: Technology.** The worldwide proliferation of advanced technology is in itself a threat. Today, only Russia and the People's Republic of China have long-range ballistic missiles that can strike the United States. Although those two countries are not regarded as threats, there is great concern over ballistic missiles being developed or purchased by rogue nations. As a recent ballistic missile demonstration by North Korea attests, rogue nations will soon pose the same long-range capabilities as China and Russia, placing the United States at risk.

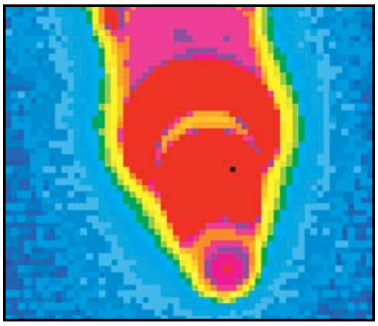


Given the proliferation of ballistic missile systems and weapons of mass destruction, protection from these threats will require a

variety of systems and technologies. BMDO is chartered within the U.S. Department of Defense to manage, direct, and execute the Ballistic Missile Defense (BMD) program in order to develop a single, integrated, and effective BMD system. BMDO's Research, Development, Test, and Evaluation (RDT&E) program is designed to develop effective systems over time using layered defenses that employ complementary sensors and weapons to engage threat targets in the boost, midcourse, and terminal phases of flight, and to deploy that capability incrementally.

The goal of the BMD system is a layered defense that provides multiple engagement opportunities along the entire flight path of a ballistic missile. Over the next three to five years, BMDO will pursue parallel technical paths to reduce schedule and cost risk in the individual RDT&E efforts. BMDO will explore and demonstrate kinetic and directed energy kill mechanisms for potential sea-, ground-, air-, and space-based operations to engage threat missiles in the boost, midcourse, and terminal phases of flight. In parallel, sensor suites and battle management and command and control (BMC^2) will be developed to form the backbone of the BMD system. These systems are listed below.

- Ground-based midcourse system, which was formerly the National Missile Defense System;
- Navy Theater Wide, which will provide a ship-based midcourse defense;



- PATRIOT Advanced Capability-3 (PAC-3), which will provide a mobile ground-based system for terminal defense;
- Theater High Altitude Area Defense (THAAD), which will provide a rapidly relocatable terminal defense;

- Navy Area, which will provide a ship-based terminal defense;
- ARROW, which is a joint program of the United States and Israel to develop a defense system for Israel;
- Medium Extended Air Defense System (MEADS), which is a joint effort of the United States, Germany, and Italy to develop a terminal defense system for the three countries.
- Airborne Laser, which will provide surveillance for boost defense;
- Space Based Laser, which will also be part of the boost defense system; and
- Space Based Infrared System-Low systems.

Because of recent strategy reviews, BMDO will transfer to the Services its responsibility for PAC-3, MEADS, and Navy Area terminal defense systems. And, in collaboration with the military services and other defense and government agencies, BMDO's integrated technology program will continue developing a plan for investment in science and technology. The plan's intent is to enhance the effectiveness of current major defense acquisition programs (MDAPs), reduce their associated costs, and strategically invest in advanced concepts and capabilities to defend the Nation against future missile threats.

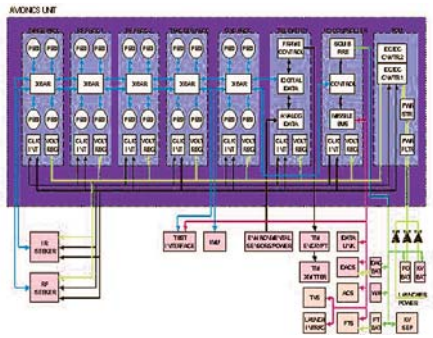
Section One

Computing and Communications

Introduction

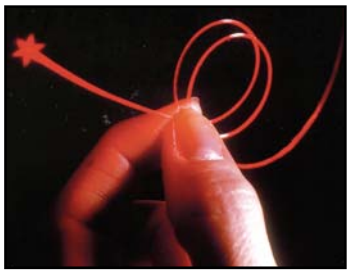
Ballistic missile defense Battle Management, Command, Control, Communications, Computers, and Intelligence (BM/C^{4}I) requires networks of sensors and surveillance systems that collect data on thousands of moving objects in space and distribute it to computers and weapon systems all over the world. These data must be processed, analyzed, stored, and transferred very quickly and without errors.

To enable global BM/C^{4}I, BMDO is investing in new computer and communications architectures. For instance, it has invested in sensor hardware and algorithms that will move decision making closer to the sensor, thereby improving discrimination and systems control. BMDO also has invested in high-speed multiplexing that will strengthen intra-computer communications. And, it has developed data compression and adaptive bandwidth management techniques that will improve networking performance. New hardware and software projects such as these will make BM/C^{4}I systems smaller, more robust, more fault tolerant, and highly optimized for rapid data processing.



Reported herein are several technology investments—high-speed network communications, the integration of computers and networks using different hardware and software configurations, and pattern analysis algorithms—that can be found in the commercial marketplace or on BMDO systems directly. Some of these technologies have found commercial success, for instance a 3-D visualization technology that is being used in dentistry, optical switching technologies, and tunable diode lasers for broadband communications. And, high-density stacked memories and processor chips are now being used for ultrahigh computation needs. Others, such as high-power, solid-state, short-wave transmitters have been used directly in BMD systems.

Laser Array Transmitters Speed Data Transmission



▲ *Data speeds through fiber-optic cables with the help of specially designed laser array transmitters from Ortel. Image courtesy of Corning, Inc.*

Ortel Corporation (Alhambra, CA) is developing a system for bundling multiple high-performance laser transmitters into a compact package for high-speed data networking. BMDO (then SDIO) began funding Ortel in 1988 to develop optical networks with terabit-per-second transfer rates. Today BMDO is using Ortel's technology to bundle a four-channel laser array in a communications transmitter to demonstrate high data-rate transfer speeds between clustered computers in the Virtual Distributed Hardware-in-the-Loop program.

The technology uses 2.5 gigabit/second lasers that precisely transmit at standard wavelengths around 1550 nm, with 200 gigahertz separations between channels. Ortel has had these products on the market since 1998. Ortel was acquired by Lucent Technologies in 2000.

Imaging System Offers 360º Panoramic View

▲ *With its 360º panoramic view, nothing can hide from Genex Technologies' OmniEye™.*

To help battle managers visualize the full scope of a missile defense campaign, Genex Technologies, Inc. (Kensington, MD), developed an omnidirectional 3-D imaging system. The company built a prototype high-speed, low-cost, multi-mode imaging system offering a 360° panoramic view.

Genex has adapted this military imaging system for individual consumers and security companies. The commercial OmniEye™ product offers up to 16 user-controlled real-time viewing windows with a resolution of 640 x 480 pixels at the standard video transmission rate. The viewing windows are controlled by software compatible with standard personal computers. In addition, the system features a rugged, portable design with no mechanical moving parts and uses many off-the-shelf components, reducing production cost.

Mini Programs Map Multi-Source Software Code

▲ *FlowLynx's product makes software engineering projects more manageable while reducing their completion time.*

Missile defense decisions are based on input from computers programmed in diverse languages such as Ada, C, C++, Cobol, and Java. When integrating these programs into one system, programmers need a vehicle to graphically map the flow of software code. FlowLynx, Inc. (Huntsville, AL), has done this with visually based software agents developed, in part, with BMDO funding. FlowLynx's product, Visual FlowCoder™ software, integrates many aspects of software analysis into one package, making engineering analysis on a system-wide scale more manageable. FlowLynx estimates that its commercial customers can complete software engineering projects in half the time or less. FlowCoder is available for most Microsoft Windows®-based operating systems and for Unix and Linux. By mid-2000, the company had sold more than $500,000 worth of FlowCoder-related tools and services to 50 licensed users such as NASA Marshall Space Flight Center, Lockheed Martin (formerly Martin Marietta), and Teledyne Brown Engineering.

High-Speed Optical Routing Switch Is Also More Reliable

▲ *Chorum's high-speed optical routing switch is changing the way networks are built.*

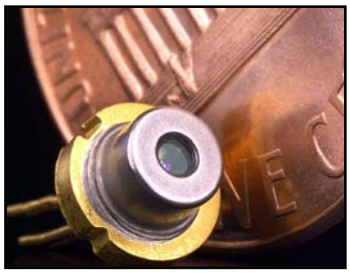
To track incoming ballistic missiles, BMDO must develop missile defense systems that analyze incoming information from satellites, radar, and a host of other systems. And, to swiftly handle information in different formats simultaneously, BMDO must have high-speed data networks in place that can disseminate it. Chorum Technologies, Inc. (Richardson, TX), developed a solid-state optical routing switch that can help reduce the cost and speed up the routing of traffic through high-capacity, fiber-optic networks. The switch features polarization manipulation, allowing it to operate with no moving parts. This will replace conventional opto-mechanical switches that have a relatively limited lifetime and require more power. Chorum is currently selling its products—like optical switches, filters, multiplexers, demultiplexers, processors, and integrated systems for advanced optical networks—to Tycom and Nortel.

Neural Network Uses Self-Learning Technology

▲ *Long a manual task, ballistic analysis is now mostly automated thanks to Intelligent Automation's RotoScan and Fuzzy CMAC technologies.*

Surveillance information flowing into missile defense systems is sorted and analyzed by computers. One way to increase efficiency is for computers to recognize and learn from previous recorded patterns. Intelligent Automation, Inc. (Rockville, MD), has been able to do this with its hybrid neural network technology called Fuzzy CMAC, a combination of fuzzy logic and a type of neural network called a cerebellar model arithmetic computer (CMAC). Intelligent Automation's Fuzzy CMAC can learn faster and more accurately than conventional CMACs. It facilitates higher performance control, plus it offers faster and better adaptation to changing characteristics during operation. Commercially, Intelligent Automation has used the Fuzzy CMAC in a scanning device called RotoScan—the chief component of the DRUGFIRE® system, which is a ballistics analysis system developed and marketed by Mnemonic Systems, Inc. RotoScan digitizes the striations (scratches) on a bullet as it blasts down the gun barrel creating, in effect, a fingerprint of the gun on the bullet. Using RotoScan, a ballistics analysis that has taken one day to complete, now can be reduced to a 30-minute process. Used by the FBI and other crime labs, DRUGFIRE has solved over 1,000 crimes and has logged sales in excess of $1.5 million.

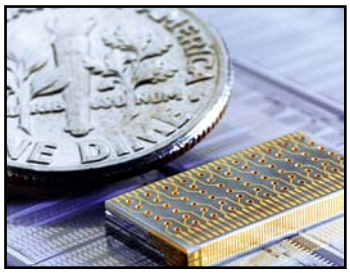
Diode Lasers Offer Fine-Tuning Capability



▲ *SpectraSensors builds tunable diode lasers that can be used in a variety of commercial applications, from optical communications to gas sensing.*

BMDO, in cooperation with NASA, funded the Jet Propulsion Laboratory (JPL; Pasadena, CA) to build a tunable diode laser that can tune to and hold specified wavelengths around 1.5 microns for high-speed optical communications used for decision making. SpectraSensors (Altadena, CA) holds an exclusive license from JPL for this technology. The license allows SpectraSensors to commercialize the tunable indium gallium arsenide phosphide laser technology at wavelengths between 1.6 to 2.03 microns. Currently, the technology is being used by El Paso Energy Corporation (Houston, TX) to detect water vapor in natural-gas pipelines. SpectraSensors is also developing a dual-laser system that can measure water vapor and carbon dioxide impurities in pipelines, replacing chemical sensors that are prone to damage. The laser-based system is less susceptible to contaminant damage than chemical sensors while offering greater sensitivity to gas impurities and a faster response time.

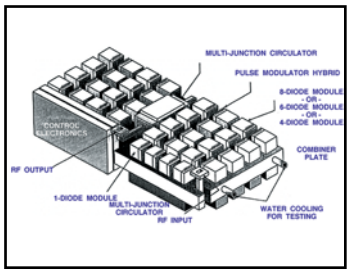
Fast Computer Chips Are Placed In Infrared Seekers



▲ *Stacking high-density computer chips, a technique developed by Irvine Sensors, allows for smaller, faster processing power.*

BMDO's technology investment in stacked computer chips has made its way back into a military system. Irvine Sensors Corporation (Costa Mesa, CA) is providing stacked high-density computer chips to Lockheed Martin for infrared seekers in the Theater High Altitude Area Defense (THAAD) program. BMDO funded research into layering microchips to produce a 3-D chip stack. Packaging chips in this manner reduces the length of chip interconnections, leading to a smaller, faster processor. Length reduction of chip interconnects reduces printed circuit board size by a factor of 16 and increases operating speed of the module. In addition, memory capacity is increased four-fold within the available volume, and overall power consumption of the module is reduced. Commercially, Irvine sells several stacked memory products, and it has a patented Neo-stack™ technology for a "computer-in- a-cube." This application is slated for demonstration under the BMDO-funded Silicon Brain development program.

Efficient High-Power Transmitter Offers Reliability



▲ *New solid-state transmitters use semiconductor materials to increase power, range, and accuracy.*

BMDO is funding the development of a new higher power, solid-state, on board transmitter designed to function more reliably with greater power and energy efficiency. The new-generation solid-state transmitter uses both gallium arsenide (GaAs) and indium phosphide (InP) to achieve increased power, range, and accuracy. Fully developed, these transmitters should double the power of existing systems while cutting the weight in half. In addition, the transmitter is designed to function at reduced capacity in case of a failure rather than shutting down.

Missile interceptors seek out the enemy warheads and destroy them. To do that, the interceptors must communicate with the ground-based radar, which locates an incoming missile and passes that information back to the interceptors, which then autonomously track the target, steer toward it, and hit it. These new transmitters will lower the cost and increase the performance of all future missile-based radar systems.

Section Two

Materials

Introduction

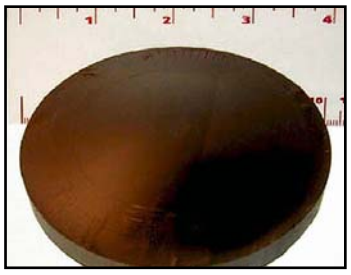
To build missiles able to withstand the rigors and harsh conditions of high-speed flight, BMDO has a keen interest in developing new families of materials that are stronger, lighter, and cheaper. New electronic materials, as well, will enable BMD systems to operate faster and at higher powers and temperatures than ever before.

Most of the current materials being developed by BMDO are intended for future defense systems, but some have the potential for improving current systems. For example, space structures for satellites and space-based interceptors must be able to retarget without jitter caused by vibrations and thermo-mechanical flutter. Land-based interceptors must withstand high-gravitational loads, heat, and structural vibration while maintaining tracking accuracy. To meet these needs, BMDO is investing in techniques for integrating instruments, like embedded sensors, into advanced composite materials and structures.

BMDO also is funding projects in electronic materials. Such technologies include a semiconductor material for high-temperature, high-power electronics and a fabrication method for crystal composites for lasers. There is also a wavelength division multiplexer made from holographic materials that allows multiple light beams to be combined into a single signal; a high-frequency transistor structure; and organic and polymer materials with unique electronic properties.

Some of the BMDO materials technologies being used commercially include a process for vapor coating electronic materials and a coating technology that improves the durability and performance of metal coatings. There are also BMDO materials technologies making their way back into the defense community. Examples of these include a method of producing aluminum and copper alloys reinforced with graphite fibers, and a fabrication process that lowers the cost of processing carbon composites while increasing their reliability.

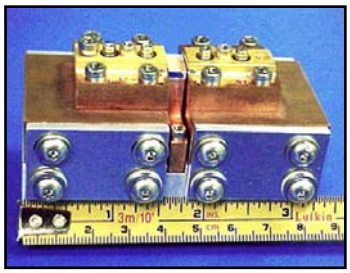
Silicon Carbide Developments Trump Silicon and Gallium Arsenide



▲ *Silicon carbide materials made by Sterling Semiconductor are essential for high-temperature and high-power electronics.*

BMDO is regularly on the lookout for materials that support high-temperature and high-power electronics, like silicon carbide (SiC). As a long-time supporter of using emerging semiconductor materials for applications such as optoelectronics, BMDO funded Sterling Semiconductor (Sterling, VA) to develop SiC wafers and epitaxial reactors for SiC deposition. SiC's wide bandgap, high electric field breakdown, high thermal conductivity, and high saturated drift velocity exceed that of silicon and gallium arsenide. Sterling Semiconductor's SiC advances caught the attention of Uniroyal Technology Corporation, prompting an acquisition that took place in May 2000. Uniroyal invested $30 million in a 50,000-square-foot facility, which will permit Sterling to expand its SiC production facilities and produce 4-inch SiC wafers, primarily for the overseas makers of SiC-based LEDs.

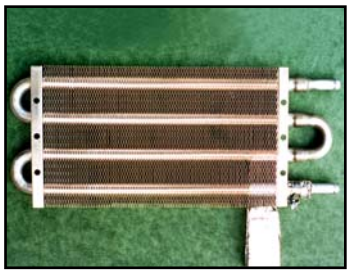
Bonding Developed For Fabricating Composite Crystals



▲ *Having discovered how to bond dissimilar crystals without damaging stress defects, Onyx Optics is opening up new markets in optoelectronics.*

BMDO has an ongoing interest in the development of high average-power lasers for displays and data storage. Onyx Optics, Inc. (Dublin, CA), developed a process for fabricating bonded YAG/sapphire crystal composites in waveguide structures as components in YAG (yttrium aluminum garnet) laser systems for these applications. The process is also used for waveguide lasers and amplifiers for LIDAR (light detection and ranging), range finders, optical communications, and semiconductor fabrication. Onyx has an adhesive-free bonding process that can combine disparate YAG and sapphire crystals without creating damaging stress defects. Because sapphire has higher mechanical strength, higher thermal conductivity, and a smaller coefficient of thermal expansion than YAG, the composites offer higher thermal shock resistance than YAG alone. Onyx Optics is successfully selling its composite crystal technology through a line of waveguide lasers that are smaller, more rugged, and more thermally stable than competing devices. Marketed by a spinoff company, Maxios Laser Corporation (Livermore, CA), Onyx's technology has led to lasers in wavelengths from 946 nanometers to 2.82 microns, which are ideal for materials marking and processing applications such as writing identifying code, text, and images on metal, semiconductors, plastic, and glass. These waveguide lasers also offer a slim profile that minimizes device size and allows heat to dissipate swiftly.

Thin-Film Coating Process Does Away With Chambers



▲ *MicroCoating Technologies has found an interesting niche applying thin-film coatings to objects with large or irregular surfaces.*

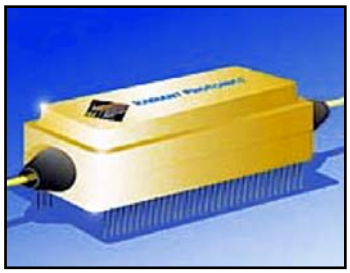
The need for vacuum chambers typically drives up the cost of chemical and physical vapor deposition, prompting BMDO's interest in new vapor coating processes. MicroCoating Technologies (Atlanta, GA) received BMDO funding to develop a low-cost, flame-assisted, thin-film coating process that deposits a wide spectrum of materials in open atmosphere conditions. Unlike other low-cost deposition technologies, this process, called combustion chemical vapor deposition (CCVD™), can produce the same high-quality coatings as current chemical and physical vapor deposition technologies. It also coat objects with large or irregular surfaces that do not easily fit in traditional coating chambers. A key feature of the CCVD process is the capability to use a precursor that costs 100-times less than the high-purity, high vapor-pressure ones used in conventional chemical vapor deposition (CVD) chambers. MicroCoating Technologies has used the CCVD process to deposit over 60 materials on various substrates from metals to plastics, and can use it to deposit complex composition films and multiple layers on substrates. There is ongoing research for potential uses of the process in the broadband telecommunications industry.

Metal Coating Process Improves Product Durability and Performance

▲ *Stronger, more durable coatings via kinetic metalization are a specialty of Inovati.*

BMDO funded the development of a coating technology to increase the durability and performance of metal coatings, primarily as a low-cost method for surface modification and coating of aluminum alloys—a requirement for numerous BMDO systems exposed to harsh environments. Inovati (Santa Barbara, CA) has developed a metal coating process for wear resistance, corrosion protection, and metal joining called kinetic metalization (KM). In addition to producing high-quality aluminum alloy coatings, the KM process does not involve environmentally dangerous aerosols typically used during surface cleaning or the hazardous solvents that competing techniques, such as electroplating, employ. Similar in principle to thermal spraying, KM produces stronger, more durable coatings by balancing the pressure and velocity of the carrier gas. Commercially, Inovati is successfully supplying KM-treated equipment racks to Hendry Telephone Products for its phone switching stations. Inovati is also working with a helium supplier incorporating a recycling system into its KM equipment for greater efficiency. The company has also been involved in projects to coat automotive heat exchangers and airplane skins.

Wavelength Division Multiplexer Packs More Information Into Single Signal



▲ *Radiant Research has developed a wavelength division multiplexer that can vastly increase the transmission capacity of fiber-optic communications systems.*

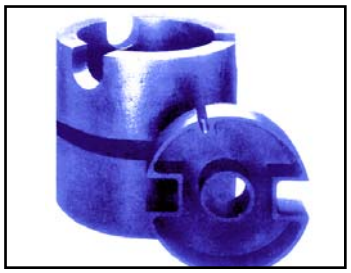
To facilitate next-generation space-based satellite-to-satellite laser communications, BMDO funded Radiant Research, Inc. (Austin, TX), to develop versatile, high-performance, wavelength division multiplexers (WDMs). These WDMs have a holographic diffraction grating that scatters light at an angle dependent on wavelength, allowing multiple light beams to be combined into a single signal. By doing so, BMDO laser communications systems will be able to pack more data in a single transmission. The amount of extra data depends on how finely WDM systems can resolve different wavelengths of light. Radiant's holographic gratings offer resolution down to 0.1 nanometer separation, suitable for use in dense WDM systems. Other WDM techniques can equal this resolution, but Radiant's holographic grating is the only technology that can work on both multi-mode (fibers that transmit more than one carrier signal) and single-mode fibers. In the commercial world, this means that Radiant's WDM technology can vastly increase the transmission capacity of fiber-optic communications systems without replacing existing fiber-optic cables. As a result, Radiant is eyeing telecommunications companies specialized in serving smaller fiber-optic markets, such as business campuses and universities. It is funneling commercial work to a spinoff company that, in September 2000, won $18 million in first-round venture funding to build a pilot manufacturing operation for optical products. By tapping a technology with such rich commercial potential, BMDO will have access to the high-performance WDM technology it needs for its laser communications systems at a much lower cost than would be possible otherwise.

Graphite-Reinforced Composites Avoid Thermal Mismatch Problems

▲ *By reinforcing aluminum and copper alloys with graphite fibers, Metal Matrix Cast Composites creates materials ideal for microwave packaging and power electronics.*

Metal Matrix Cast Composites, Inc. (Waltham, MA), has developed a method of producing aluminum and copper alloys reinforced with graphite fibers. A ballistic missile defense system is already putting this materials technology to work. Metal Matrix has a $500,000 contract with Raytheon to supply low-density, high-stiffness parts for upper-stage housings for the Navy-based Theater Wide Standard Missile-3. Using a casting process also funded by BMDO, the alloys have controlled orientations that achieve a high thermal conductivity approaching that of pure copper or aluminum. As such, the materials possess the precisely controlled thermal expansion required for electronics systems. The casting process avoids any associated thermal mismatch problems that typically occur when the heat sink has a different coefficient of thermal expansion (CTE) than the semiconductor device or ceramic substrate. These alloys have closely matched CTE to the semiconductor package, so the chips can be brazed or soldered to produce high conductivity, a high heat transfer interface, and overall superior performance. The alloys are competitively priced due to the elimination of labor-intensive production processes associated with most composite manufacturing. One of it's customers, Ixion Technologies, a leader in the advanced electronics packaging market, expects sales of its products incorporating Metal Matrix's material to hit between $15 and $25 million by 2002.

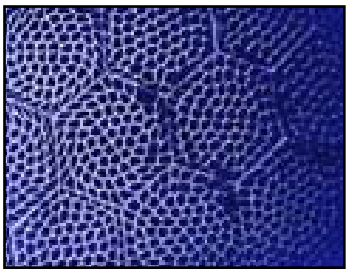
Carbon Composite Insulating Material Is Sturdy



▲ *Fiber Materials' temperature resistant material, FiberForm®, can be formed into boards, cylinders, and complex shapes.*

Fiber Materials, Inc. (Biddeford, ME), has developed innovative fabrication processes that lower carbon composite processing costs and increase the reliability of carbon composites. This technology is already being used in Theater High Altitude Area Defense (THAAD) through Lockheed Martin, United Technologies, and Loral. This fabrication process has cut the cost of quartz phenolic nose tips by 75 percent over nose tips in other strategic defense systems. The company has made carbon/carbon nozzles that are 30 percent to 50 percent cheaper than those in other defense systems. Fiber Materials' insulating materials, marketed as FiberForm®, are based on thick mats of chopped carbon fibers coated with a resin binder and can be shaped into boards, cylinders, and complex shapes. The structural materials, marketed as Commercial Carbon Composites (C^3), employ overlapping layers of woven carbon fiber fabric and a relatively dense carbon matrix. These materials serve as heat shields, heating elements, structural supports, clamps, and fasteners in hot environments. Commercially, Fiber Materials annually sells between 30 and 50 tons of FiberForm thermal insulation for vacuum and inert industrial furnaces that heat-treat metals, ceramics, and carbides in applications such as fabricating turbine blades. The product can also be used in vacuum furnaces that grow crystals for the semiconductor industry.

Material Used For Diverter Valves Is Tough Stuff



▲ *Fibrous monolith processing technology developed by Advanced Ceramics creates an interpenetrating microstructure that is very tough and shock resistant.*

To operate in a harsh missile defense environment, BMDO funded the development of composite materials that are sturdy and can withstand the rigors of space. Advanced Ceramics Research, Inc. (Tucson, AZ), is developing for Thiokol, hafnium-carbide/tungsten-rhenium composites for carbon diverter valves, a component of the Standard Missile-3's solid divert and attitude control system. Significant cost savings are expected with performance up to, or better than, specifications for current materials. Advanced Ceramics' fibrous monolith processing technology creates an interpenetrating microstructure that offers toughness and thermal shock resistance. It allows complex composite architectures to be made from low-cost powders and polymers. A commercial investor in the technology is Varian, a leading x-ray tube manufacturer. In partnership with Advanced Ceramics, Varian is testing the material for use in computer-aided tomography (CAT) scanners. Advanced Ceramics plans to develop and sell x-ray targets for x-ray tubes in CAT scanners providing superior performance over current CAT scanners.

Section Three

Sensors and Tracking

Introduction

To identify and intercept a ballistic missile in flight, BMDO supports the development of increasingly robust and sophisticated sensor systems that range across the entire electromagnetic spectrum. These sensor technologies will enable the detection and tracking of a missile signature from ultraviolet to infrared wavelengths, as well as provide notification of a nuclear event or a laser or radio frequency attack.

Sensors and associated sensing systems function as the eyes of a BMD system, providing early warning of attack, target detection, target classification, tracking, and kill assessment. The most crucial sensors travel onboard the terminal phase interceptor, which flies out to destroy the incoming missile. Interceptor sensors and associated decision making systems must be rugged, reliable, and fast, and must be customized for their operating environment. For interceptor sensor systems that work completely within the atmosphere, sensors must collect and analyze information in near real time, while traveling six times the speed of sound, which is an extremely bumpy and hot environment. Sensor systems for interceptors that travel outside earth's atmosphere (exo-atmospheric) must work even quicker because both they and their targets are moving toward each other at higher speeds, and they must work in the harsh vacuum of outer space. In addition, exo-atmospheric sensor systems must be able to discriminate between the target and possible decoys it may release while in space.

To meet these needs, BMDO is currently investing in passive focal plane imaging technology from long-wave infrared to ultraviolet, as well as lightweight, compact, and efficient fixed-frequency radiation sources. Some of these technologies have found commercial success, including a technology to extend monopulse laser radar tracking techniques that has had commercial success in laser vision correction. Other technologies funded by BMDO for direct use in defense systems include an improved inertial measurement unit, solid-state infrared seekers, new high-sensitivity focal plane arrays, and long-range laser radar.

Laser Radar Tracking Works With Optics

▲ *LADARVision®, developed by Autonomous Technologies, uses laser radar technology to improve vision correction procedures.*

A key component of ballistic missile defense is radar tracking. Autonomous Technologies Corporation (Orlando, FL) received BMDO funding to extend monopulse laser radar tracking techniques to the optical domain for fast, precise tracking. This radar technique is especially attractive because of its capability to transmit and receive signals from different locations, which also allows signals to be received at a greater distance from the transmitter. Autonomous Technologies' heterodyne Doppler LADAR (laser radar) provides monopulse tracking using advanced digital recovery techniques. The technology offers low error rates for wide-bandwidth tracking, high clutter rejection from ablated debris, isolation from false target fluctuations, and unique antenna beams for high tracking accuracy.

The company has successfully applied this technology commercially for rapid, low-cost eye tracking with its LADARVision® Excimer Laser System, a laser vision correction device that helps optimize laser vision correction by combining active tracking and small-beam corneal shaping. The system compensates for involuntary eye motion by adapting object detection and ranging technology, originally developed for missile targeting and space docking systems, to track irregular eye movements.

In 1999, Summit Technology, which develops and manufactures the laser systems used to correct faulty vision, acquired Autonomous. A year later, Alcon Surgical, the eye care unit of food giant Nestle, purchased the newly formed Summit Autonomous. Today, eye surgeons use Alcon's main product, the LADARVision® Excimer System, in laser eye surgeries that treat nearsightedness, farsightedness, and astigmatism.

Inertial Measurement Units Aid Seekers

▲ *Inertial measurement units sense and verify interceptor orientation and acceleration.*

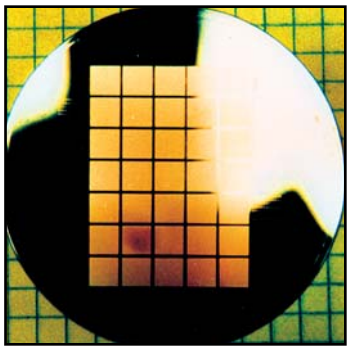
BMDO is funding the development of a new seeker that combines the interceptor's attitude control system with a highly accurate inertial measurement unit (IMU) and high-speed data processing hardware and software to track incoming missiles. This advanced "strapdown" infrared seeker will incorporate a high-speed IMU that senses and verifies the interceptor's orientation and acceleration. One near-term IMU program involves adding military refinement to an existing off-the-shelf Honeywell interferometric fiber-optic gyroscope. Another approach is to repackage a commercial Honeywell ring laser gyroscope with an additional high-speed read-out. A longer-term investment is being planned for micro-electromechanical system (MEMS) IMUs to meet future interceptor requirements. These MEMS IMUs could benefit missile defense interceptor systems by lowering cost and power requirements by 95 percent, reducing weight by 67 percent, and needing only 76 percent of the volume of previous systems.

Infrared Seekers Eliminate Need For Moving Parts

▲ *A new "strapdown" approach to infrared seekers will lead to significant size and weight reductions of interceptor kill vehicles.*

Current passive infrared seeker systems use a gimbal that rotates to compensate for motion between the interceptor and its target. To eliminate the moving parts and refine and improve infrared target tracking and discrimination, the program is developing and testing a new "strapdown" infrared seeker. The device incorporates a highly accurate inertial measurement unit (IMU), a high-speed data processor, and new processing algorithms. This new strapdown seeker concept has approximately 80 percent fewer parts, weighs 60 percent less than the current gimbaled seeker, and will allow for a dramatically smaller window. The smaller window will, in turn, reduce cooling requirements and permit a smaller forebody, decreasing the overall size and weight of the interceptor kill vehicle.

Infrared Focal Plane Arrays Offer Heightened Sensitivity

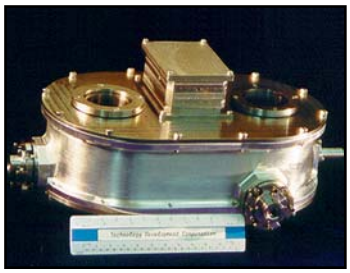


▲ *Improving the resolution of focal plane arrays will enhance target discrimination capabilities.*

Focal plane arrays (FPAs) are the eyes of a kill vehicle. They sense the heat signature given off by moving targets. The more sensitive the FPA, the sooner the target can be identified and engaged. To provide more precise target tracking and discrimination, BMDO is developing advanced infrared FPAs. The goals of the program are to reduce the mass and complexity of the electronics while improving the sensor's resolution. Better resolution will provide longer acquisition range, enhanced tracking, and better discrimination. Reducing mass will give the interceptor increased agility.

BMDO is emphasizing development of multi-color FPAs that simultaneously receive signals in two or more wavebands. The ability to compare and combine target information from multiple wavebands will greatly increase the discrimination of targets within a cluster. Wavebands for the interceptor seeker will be optimized for specific scenarios, including information on target characteristics and background clutter.

Long-Range Laser Radars Have Sharp Target Capability



▲ *Lightweight, compact, long-range laser radar can quickly identify real missiles from decoys.*

Radar systems track and characterize targets by sending out a pulse of radio frequency radiation and listening for the signal as it bounces off of the target. Laser radar (LADAR) functions the same way but with laser light. Operation at these shorter optical wavelengths improves target resolution and provides a more accurate dynamic picture. On-board data fusion from an active LADAR and passive IR sensor can provide a complete characterization of the objects in a threat cluster, including size, shape, range, range-rate, spin, and other dynamic features. To extract dynamic features from the target set at long ranges, the BMDO technology program is addressing the challenge of developing LADAR with ranges of 350 km in the exo-atmosphere environment. Although long acquisition ranges are necessary, the key requirement is to identify the credible objects from decoys as quickly as possible. These radar systems are currently being designed for Navy Theater Wide ship-based, upper-tier defense and National Missile Defense.

Section Four

Energy Management and Propulsion

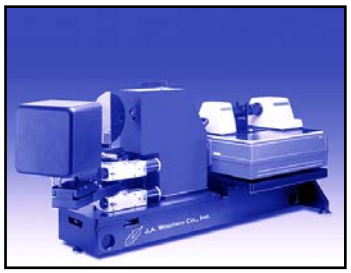
Introduction

High-powered electronics generate heat and often need to be cooled to work effectively. The cooling of sensitive electronics along with other issues, such as thermal management of heat-generating laser arrays and power sources, are some of the energy management problems that BMDO hopes to solve. BMDO is also examining new propulsion technology to add capability and solve energy management problems.

To develop both energy and propulsion technologies, BMDO is investing in portable, or mobile, compact power sources and power conditioning devices, space-based power sources from 0.5 to 5 kilowatts that can withstand high natural radiation levels, satellite energy storage systems, batteries with cycle lifetimes of up to 40,000 cycles, and low-mass or miniature interceptors that require small, efficient divert thruster propulsion systems.

Two BMDO-funded technologies in this area have met with considerable commercial success. One is an electrochromatic material that can vary the amount of light and heat it transmits. The other is a compact metal cooling unit that offers a higher heat transfer rate. In addition, there are several technologies being used in both military and commercial systems such as a radiation-hardened accelerometer, a material used to protect thrusters, and a durable pulse-power device. And, while not intended as a commercial product, BMDO also has funded the development of non-thermal batteries to reduce heat in interceptors.

Electrochromic Materials Diffuse Heat Transmission



▲ *Research in electrochromic materials led to the development of spectroscopic ellipsometers now marketed by J.A. Woollam.*

To mitigate heat buildup in the tight confines of a spacecraft, BMDO funded J.A. Woollam Company, Inc. (Lincoln, NE), to develop an electrically controlled IR filter that can vary the amount of light and heat it allows through. Woollam has demonstrated this technology in a thin-film structure of tungsten oxide and nickel oxide, operating in the mid-infrared (1 to 30 microns) range that has a potential for controlling up to 70 percent of its emissivity. In the course of creating the electrochromic materials, Woollam also developed expertise in optical and thermal measurements. Currently, the company produces a line of spectroscopic ellipsometers that test the chemical properties of materials with polarized light more thoroughly than standard spectroscopy testing instruments. In 1999, Woollam tallied sales of $10 million for its ellipsometers and associated services. Of the five ellipsometer models Woollam offers, the newest operates in the IR range and others offer capabilities such as testing epilayer thicknesses, doping densities in semiconductors, and chemically bonding information on a nanometer scale.

Compact Metal Cooling Unit Has High Heat Transfer Rate

▲ *Using heat sink technology, Thermacore came up with a way to cool hot microprocessors in portable computers.*

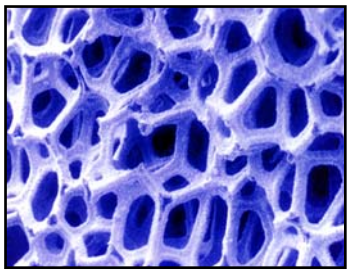
Laser arrays, when grouped together for multi-wavelength communications applications, can generate a substantial amount of heat, limiting their use in some heat-sensitive applications. Thermacore (Lancaster, PA) has developed a compact cooling unit that uses a thermally conductive, porous copper matrix to achieve high heat transfer rates for heat control in applications like bundled laser arrays. An external pump or blower forces a coolant, like water or helium, through the porous metal, adsorbing the heat and transferring it to the fluid. This device is ideal for laser diode and light-emitting diode arrays as well as for high-energy consumer electronic devices because of its size and heat transfer capacity. Commercially marketed under the name ThermaCube™, this porous metal cooling technology is used to remove heat from small devices with high heat fluxes. From high-density microchip circuitry to tightly packed laser diode arrays, compact electronics require innovative methods of pulling excess heat out of a small area. ThermaCube cools 20 percent more effectively than competing technologies and can be customized for other applications. Thermacore's miniature heat pipe technology, some of which was originally funded by SDIO/BMDO, has been successfully applied to Intel Pentium® processor notebook computers.

Radiation-Hardened Accelerometer Finds Place In Missile Interceptor

▲ *Millions of cars were equipped with air bag systems triggered by Silicon Designs' accelerometer.*

Accelerometers measure changes in motion. Accurate information on these changes is crucial to missile guidance for ballistic missile defense. With BMDO's help, Silicon Designs (Issaquah, WA) has developed a small, highly accurate, solid-state, radiation-hardened accelerometer that is being used both by the military and in automobile safety systems. The military has incorporated the accelerometers into safe-and-arm devices for the PAC-3 missile interceptor. Commercially, Silicon Designs had licensing agreements with the Ford Motor Company and TRW, Inc., who produced modified versions for automotive air bag sensors. Produced at a cost of $5 each, these sensors were installed in about 25 million automobiles worldwide. Due to commercialization and mass production, the Silicon Designs' accelerometers cost about 40 percent less than when first introduced.

Advanced Materials Offer Enhanced Protection and Reduced Cost



▲ *A synthetic material once used to insulate rocket nozzles is now providing more support for weakened spines, according to Ultramet.*

High-performance materials capable of deflecting intense heat are a key element to protect rocket thrusters. BMDO funded Ultramet, Inc. (Pacoima, CA), for several advanced materials research projects, including oxidation protection of carbon composites, ultrahigh temperature low-erosion materials, zero-erosion throats for solid propellants, ultra-lightweight heat temperature structural materials, and inexpensive high-performance divert thrusters. Ultramet's work on divert thrusters is aimed at reducing by 50 to 75 percent the manufacturing cost (which accounts for 70 percent of the total cost) of a thruster nozzle. This is possible by using a thin rhenium shell with carbon composite reinforcement—offsetting the high cost of the rhenium normally used. This technology has been successfully commercialized while concurrently finding a place in current military systems. For BMDO use, Ultramet is developing rhenium thrusters under a subcontract with Thiokol and AlliedSignal (now part of Honeywell). Commercially, Ultramet is working with Implex to produce Hedrocel® bone implants. This product is strong enough to mimic the bone and yet is also porous, allowing the bone to grow into the implant. Mass production of Hedrocel implants has led to reduced cost, improved production efficiency, and shortened delivery times for other products, including those used in military applications.

Pulse-Power Module Offers Energy Recovery

▲ *Science Research Laboratory has develop a power source that is being used in excimer lasers deployed in lithography steppers worldwide.*

Durable pulse-power devices capable of operating at high pulse rates while maintaining high power were developed by Science Research Laboratory (SRL; Somerville, MA) with support from BMDO. SRL, in turn, has licensed the solid-state pulse power module (SSPPM) to Cymer, Inc., for use in its excimer laser system for electronics processing. Cymer used the SSPPM to replace the thyratron-based drivers in their laser systems and is currently the world's leading supplier of krypton fluoride lasers, with over 90 percent share of the commercial lithography market. Cymer sells its laser to the lithography industry's stepper suppliers, such as Nikon and Canon in Japan, ASML in Holland, and Silicon Valley Group-Lithography in the United States. These companies, in turn, sell their technology to the major semiconductor producers, such as Intel.

By replacing its thyratron circuit with SRL's all solid-state system, Cymer was able to increase the lifetime of its pulse-power drive from 1 billion shots (two weeks of operations) to over 100 billion shots (four years of operations). In addition, the energy recovery circuits extended the lifetime of the discharge electrodes and the working gas by more than a factor of 10. Together, these improvements have reduced the annual operating expense of the laser systems by 80 percent. This solid-state lithography power source technology is currently used in the production of nearly *every* integrated circuit incorporated by DOD.